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(54) Electrohydraulic system.

(57) In a die casting machine that includes a shot cylinder having a ram for injecting metal into a die cavity, an electrohydraulic system for controlling operation of the shot cylinder includes an actuator coupled to the shot cylinder ram. A valve supplies hydraulic fluid to the actuator cylinder as a function of valve control signals. Microprocessor-based digital control electronics includes memory for storing a desired ram velocity profile as an incremental function of ram position. The control circuitry is responsive to signals from a sensor coupled to the actuator, indicative of position at the ram, for retrieving corresponding velocity signals from memory and supplying control signals to the valve as a function of such profile velocity signals. The control circuitry further includes facility for adjusting impact of the shot cylinder ram at the end of a cavity-filling stroke as a function of ram and actuator position and/or pressure, independently of the velocity/position profile, to reduce separation and flashing at the die cavity, and to reduce impact wear and fatigue on the overall die casting machine. A keyboard and associated operator display provide operator programmability and selection from a plurality of velocity/position profiles. The actuator and cylinder ram may be advanced in a manual mode of operation for adjustment and calibration proposes. A display associated with the keyboard graphically illustrates desired and actual velocity/position profiles during operation, together with a profile of actuator drive pressure verses position.

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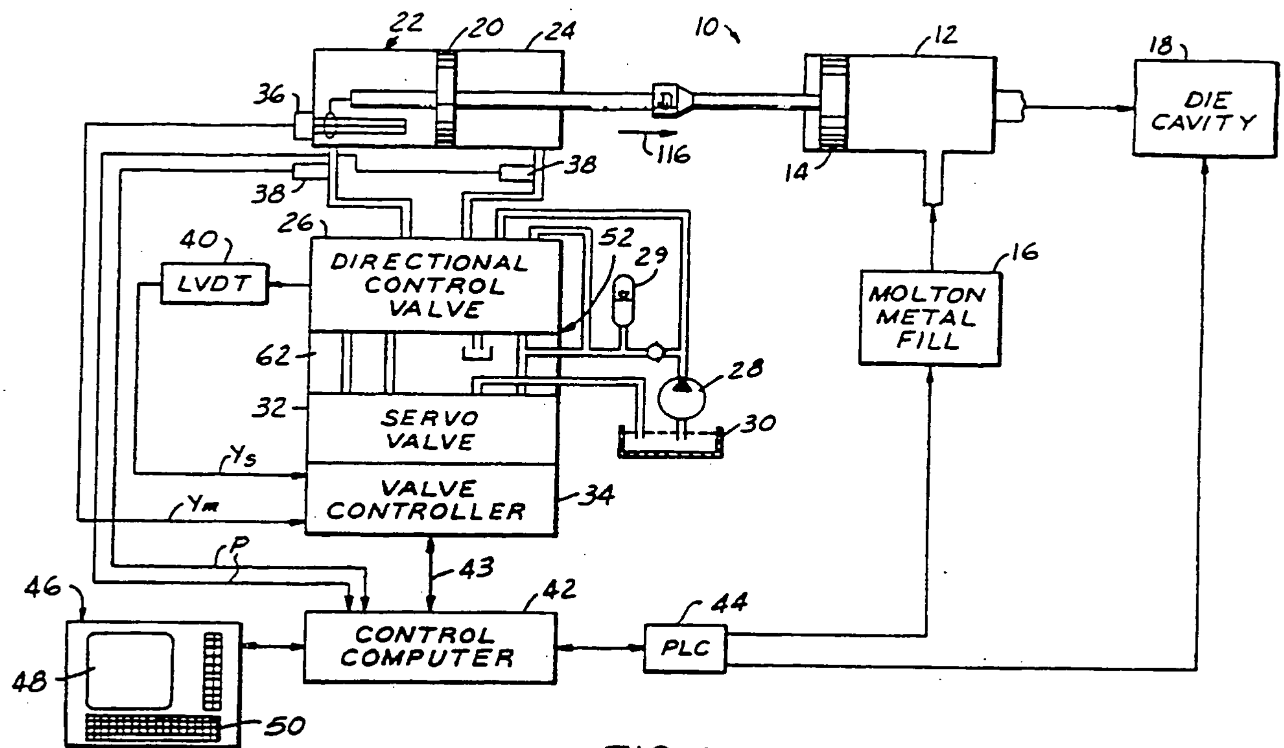

22
20
24
10
12
18
36
DIE CAVITY
116
14
38
38
26
40
52
29
16
LVDT
DIRECTIONAL CONTROL VALVE
MOLTON METAL FILL
62
28
32
SERVO VALVE
30
Y_s
VALVE CONTROLLER
34
Y_m
P
43
46
42
44
CONTROL COMPUTER
PLC
48
50

FIG. 1

more particularly to control of shot cylinder ram velocity in a die casting machine.

Background and Objects of the Invention

There are numerous applications in the electrohydraulic control field in which it is desired to control motion at an actuator system and load. In a die casting machine, for example, it is desirable closely to control the profile of motion at the so-called shot cylinder that pushes molten metal into the machine die cavity. Specifically, velocity of the shot cylinder ram must be closely controlled as a function of ram position to obtain optimum machine efficiency and throughput, while maintaining product quality and reducing material waste through die separation and flashing, etc. Wear at the cylinder and die cavity are also reduced, and machine productivity therefore increased, when both velocity and stroke of the shot cylinder ram can be closely controlled and tailored to die cavity volume and configuration.

It is therefore a general object of the present invention to provide an electrohydraulic actuator system that obtains enhanced and precise control of motion at the actuator and load. Another object of the present invention is to provide a system of the described character that embodies state-of-the-art electronic control capability, and yet is easy and economical to implement both in new system construction and in retrofit of existing systems.

A further and more specific object of the present invention is to provide an electrohydraulic system for controlling velocity at an actuator load, such as the shot cylinder of a die casting machine, as a precise yet programmable function of position. A related object of the invention is to provide a shot cylinder control system for a die casting machine that includes facility for programming and storing a plurality of operator-selectable velocity versus position control profiles, for adjustment of impact force at the end of the ram stroke for reducing die separation and flashing at the machine, and/or for graphic display of desired and/or

An electrohydraulic system for controlling motion at a load coupled to a hydraulic actuator in accordance with a first important aspect of the present invention includes an electrohydraulic valve having a valve element. Hydraulic fluid is supplied to the actuator as a function of position of the valve element, which in turn is controlled by electronic valve control signals supplied to the valve. A first position sensor is coupled to the actuator for providing a corresponding signal as a function of motion at the actuator and load. A second position sensor is coupled to the movable element of the valve for providing a corresponding sensor signal as a function of motion at the valve element. Control electronics includes an inner servo loop that supplies control signals to the valve as a function of a differences between a valve command input signal and the signal from the second sensor coupled to the valve element. An outer servo loop supplies a load position error signal as a function of a difference between a load position command input signal and the signal from the first sensor coupled to the actuator and load. A switch is controlled to select between the load position error signal and a separate valve element position command signal to provide the valve command signal to the inner servo loop. Thus, the control electronics, which is preferably microprocessor-based, includes facility for programmed or manual selection of dual control modes of operation for enhanced control flexibility and precision.

In accordance with a second important aspect of the present invention, the control electronics includes facility for entering a desired profile of velocity versus position or time at the actuator and load. Signals indicative of actual position at the actuator and load are received from the sensor coupled to the load, and corresponding command signals are supplied to the valve for obtaining desired load velocity. Preferably, the control electronics is microprocessor-based and includes facility for receiving and storing a plurality of desired velocity/position profiles and selecting from among the plurality of prestored profiles for operation of the system. Actual velocity/position profile is

event that a modification is desired, the operator may shift screen cursor 104 to the appropriate screen location, and enter the corresponding desired change in position or velocity. A title 106 is selected by the operator and assigned to the profile, and the profile is stored under that title in memory 72 (FIG. 4) by depression of the ENTER key at keyboard 50. Thereafter, the profile of FIG. 6 may be modified as desired by simply recalling the profile by title (GBNEW in the example of FIG. 6) and entering desired changes.

In the manual and automatic modes of operation, screen 48 is configured to contain two graphic displays 108, 110 (FIG. 7). Display 108 contains superimposed images of desired and actual position/velocity profiles, and display 110 illustrates actual pressure/position profile obtained during system operation. Initially, in a manual mode of operation for which an exemplary display is illustrated in FIG. 7, the operator selects a preprogrammed velocity/position profile, and this profile 112 is displayed. In the exemplary profile 112, the operator desires to increase velocity at actuator 22 and shot cylinder 12 (FIG. 1) rapidly to a velocity of 220 inches per second, and to maintain this velocity throughout the entire stroke of 22 inches. (Stroke length is selectable, with different lengths being illustrated in FIGS. 6 and 7 for purposes of example.) Upon depression of the F1 function key at keyboard 50, actuator 22 is driver by computer 42 and controller 34 through a complete stroke in the cavity-filling direction 116 (FIG. 1). At each incremental position of actuator piston 20, the corresponding actual velocity is determined as a function of a change in position feedback signal Ym, and the computed velocity is graphically displayed at 114. Likewise, actuator drive pressure P (FIG. 1) is read for incremental display at 110. The operator may thus observe actual versus desired velocity/position profile, as well as changes in hydraulic pressure corresponding to such profile. Desired modifications may be made by returning to the profile editor mode of operation (FIG. 6). Upon completion of a stroke, the shot cylinder and actuator velocity/position profile 114 and pressure profile 110 of the most recent ten shots, preferably in different colors so that the operator may observe any changes in operation. Each "shot" is initiated by a command signal from PLC, which among other functions correspondingly controls reservoir 16 and die cavity 18 (FIG. 1). Status information is transmitted to PLC for management information and control purposes.

In a calibration mode of operation, the operator has the ability to calibrate the end positions of the actuator, and also to adjust actuator speed through adjustment of fluid flow to the actuator from directional control valve 26. Return velocity of actuator 22 and ram 14 are preferably constant, and set at this point. Likewise, in a system configuration mode of operation, desired maximum velocities, pressure, stroke length and other parameters may be entered by the operator.

Velocity of the actuator and shot cylinder at the end of a cavity-filling stroke, and thus impact of the shot cylinder when the cavity is full, may be adjusted to reduce separation of the die elements and consequent flash of material out of the die. This is accomplished by selection of the desired impact level (0 through 9) in the configuration mode, the shot profile entry/edit mode or the automatic mode. The selected value corresponds to a predefined acceleration profile near the end of the stroke. This profile is based upon the actual position of actuator 22 and/or the pressure signals from sensors 38.

Claims

1. An electrohydraulic system for controlling motion of a load (10) coupled to hydraulic actuation means (22), said system comprising
electrohydraulic valve means (26, 32) that includes a valve element (54), means (56) for supplying hydraulic fluid to said actuation means (22) as a function of position of said valve element (54), and means (32) responsive to electronic valve control signals (U) for controlling position of said valve element (54), and

means for receiving first (Yc) and second (Ysc) command signals as functions of desired motion at the load (10) and valve element (54) respectively, means (74) for providing an error signal (E) as a function of a difference between said first command signal (Yc) and said first sensor signal (Ym), means (56) for selecting between said error signal (E) and said second command signal (Ysc) to provide a command control signal (R), and means (88) for providing said valve control signals (U) as a function of a difference between said command control signal (R) and said second sensor signal (Ys).

2. The system set forth in claim 1
wherein said first and second command signals (Yc, Ysc) comprises respective position command signals, and
wherein said first and second sensors (36, 40) supply said sensor signals (Ym, Ys) as respective functions of position at said load (10) and valve element (54).

3. The system set forth in claim 2
wherein said error-signal providing means (74) includes means (76) for differentiating said first sensor signal (Ym).

4. The system set forth in claim 2 or 3
wherein said electronic valve control means (34) comprise an inner electronic servo control loop (94) that includes means (88) for supplying said valve control signals (U) as a function of a difference between said valve command signal (R) and said second sensor signal (Ys),
an outer electronic servo control loop (96) that includes means (74) for receiving a load position command signal (Yc), and means (74) for supplyingn a load position error signal (E) as a function of a difference between said load position command signal (yc) and said first sensor signal (Ym),
means (86) for receiving a valve element position command signal (Ysc), and
means (86) for selecting between said load position error signal (E) and said valve element position command signal (Ysc) to provide said valve command signal (R) to said inner servo loop (94).

5. The system set forth in claim 4
wherein said outer servo control loop (96) includes means (76) for differentiating said first sensor signal (Ym) to filter said first sensor signal.

6. An electrohydraulic system set forth in any of claims 1 to 5 further comprising
control means (42) for supplying said input commands (Yc, Ysc) to said valve controller (34),
characterized in that said control means (34) includes means for controlling profile of load velocity versus position comprising
means (50) for entering a desired profile of velocity versus position at said load,
means (72) for receiving and storing said desired profile,
means (43, 66) for receiving signals (Ym) from said actuator means (22) indicative of position at said load (10) and
means (64) responsive to said receiving-and-storing means (43, 66, 72) and to said position-indicating signals (Ym) for supplying said input command signals (Yc, Ysc) to said valve controller (34).

7. The system set forth in claim 6
wherein said receiving-and-storing means comprises means (72) for receiving and storing a plurality of said desired profiles, and means (46, 50) for selecting among said plurality of profiles for operation of said system.

8. The system set forth in claim 6 or 7
further comprising means (48) for graphically displaying said desired velocity/position profile.

9. The system set forth in claim 8
wherein said graphically-displaying means (48) further includes means responsive to said position-indicative signals (Ym) for graphically displaying actual velocity/position profile at said load (10).

10. The system set forth in claim 9
wherein said graphically-displaying means (48) includes means (108) for displaying said actual profile superimposed on said desired profile.

11. The system set forth in any of claims 1 to 10
further comprising means (38) for supplying a pressure signal (P) as a function of hydraulic fluid pressure at said actuator (22), and wherein graphically-displaying means (48) further comprises means (64, 66, 68, 110) responsive to said pressure signal (P) and to said position-indicative signals (Ym) for displaying profile of pressure versus position at said actuator.

12. The system set forth in any of claims 6 to 11
wherein said control means (42) further includes means for selectively adjusting velocity or impact at a limit of travel of said load (10) independently of said profile.

13. The system set forth in any of claims 6 to 12
wherein said control means (42) comprises menu-driven microprocessor-based control means (70).

14. The system set forth in any of claims 6 to 13
wherein said profile-entering means (50) comprises means for selectively varying parameters of said profile.

15. The system set forth in any of claims 6 to 14
wherein said control means (42)

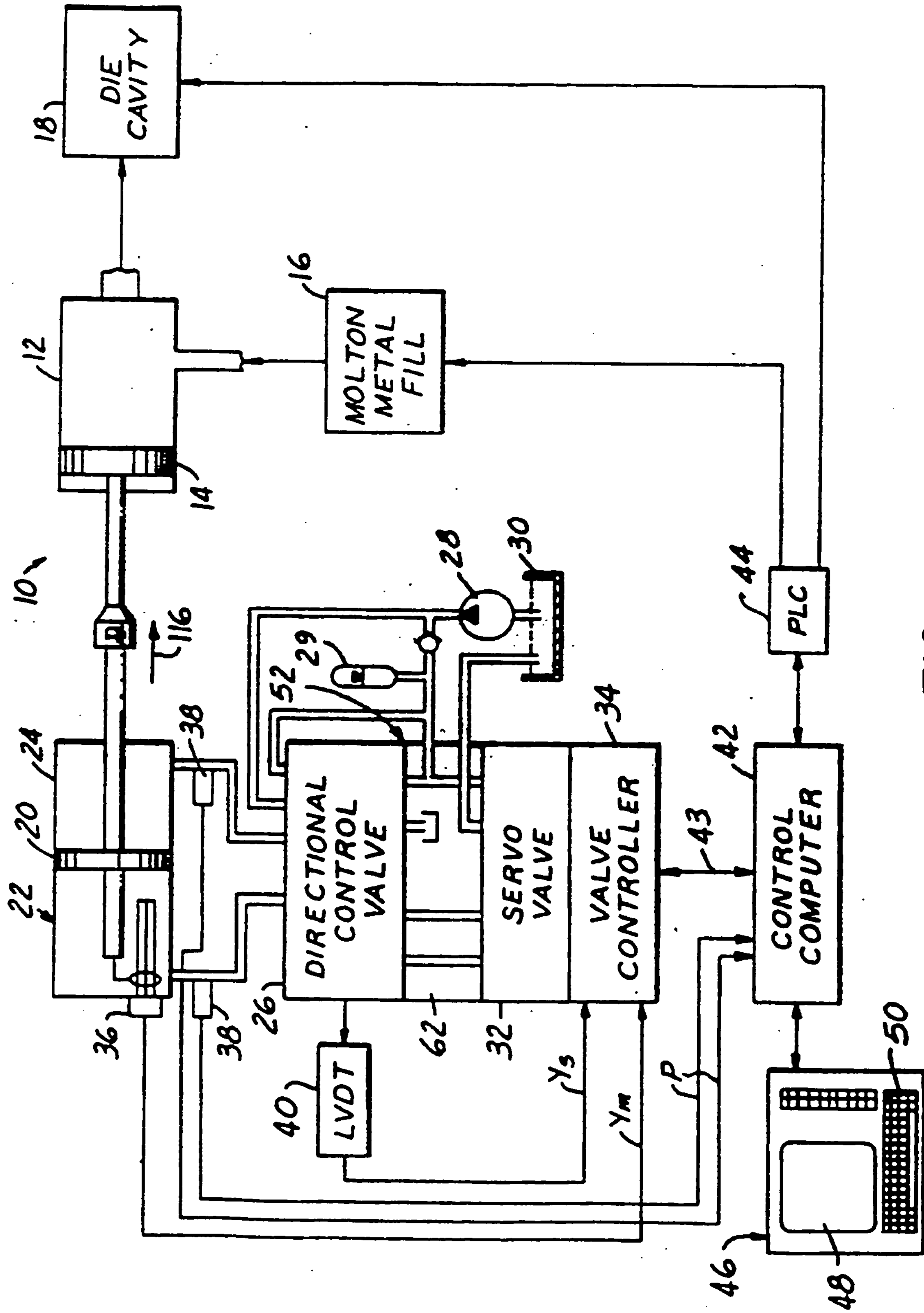
16. The system set forth in any of claims 1 to

15
wherein said load comp[illegible] shot cylinder (12) having a ram (14) for ir[illegible] metal into a die cavity (18) of a die castin[illegible] [illegible]e (10).

17. The system of [illegible] wherein said control means (42) includes means (102, [illegible]) for controlling profile of shot cylinder ram ve[illegible]ty versus position comprising
digital memory means (72) for storing a desired ram velocity profile as an incremental function of ram position,
means (64) coupled to said memory means (72) and responsive to increments of said position-indicative signal (Ym) for retrieving from said memory means corresponding velocity signals, and
means for supplying said valve control signals as a function of said velocity signals.

18. The system set forth in claim 17 wherein said memory means (72) further includes means for storing adjusted impact control data associated with each said profile.

19. The system set forth in any of claims 6 to 18 wherein said control means (42) further includes means for optionally entering a desired profile of velocity versus time, and means for supplying said input command signals as a function of said velocity/time profile.


DIE CAVITY
MOLTON METAL FILL
DIRECTIONAL CONTROL VALVE
SERVO VALVE
VALVE CONTROLLER
CONTROL COMPUTER
PLC
LVDT
Ys
Ym
P
10
12
14
16
18
20
22
24
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46
48
50
52
62
116

FIG. 1

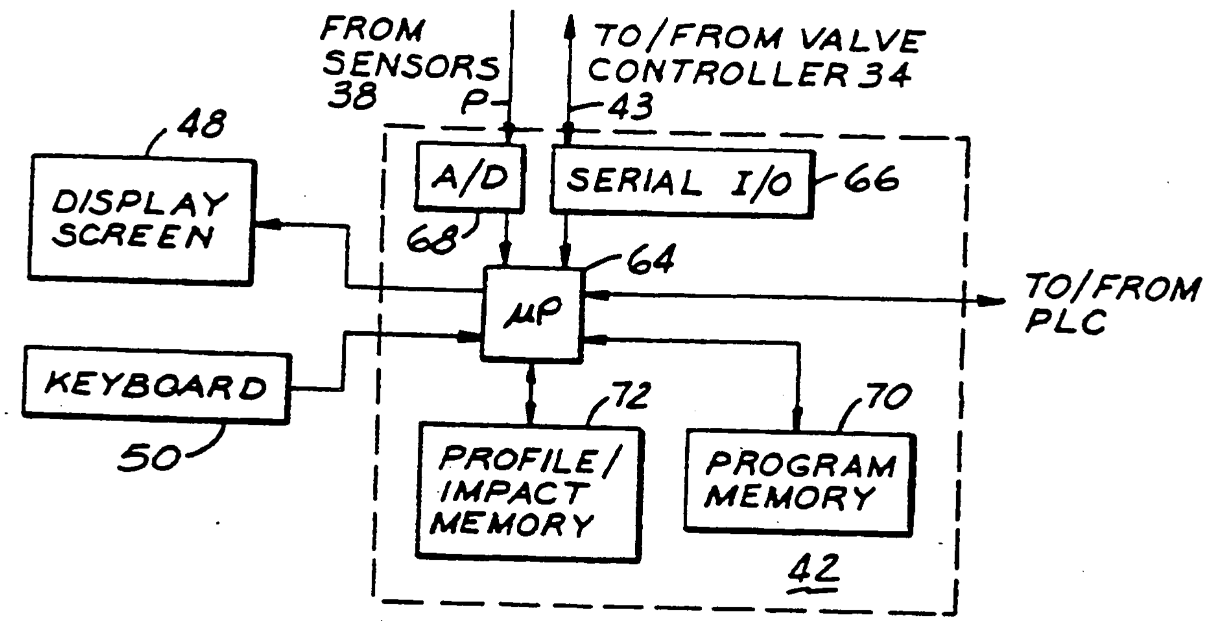
FROM SENSORS 38
P
TO/FROM VALVE CONTROLLER 34
43
48
DISPLAY SCREEN
A/D
68
SERIAL I/O
66
64
μP
TO/FROM PLC
KEYBOARD
50
72
PROFILE/ IMPACT MEMORY
70
PROGRAM MEMORY
42

FIG.4

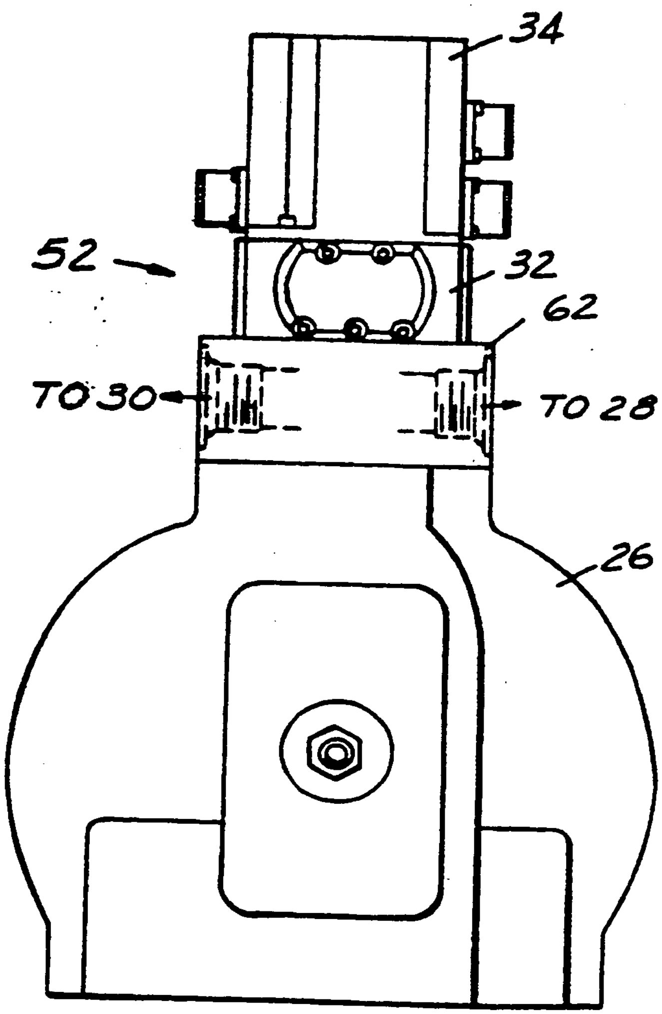
34
52
32
62
TO 30
TO 28
26

FIG.2

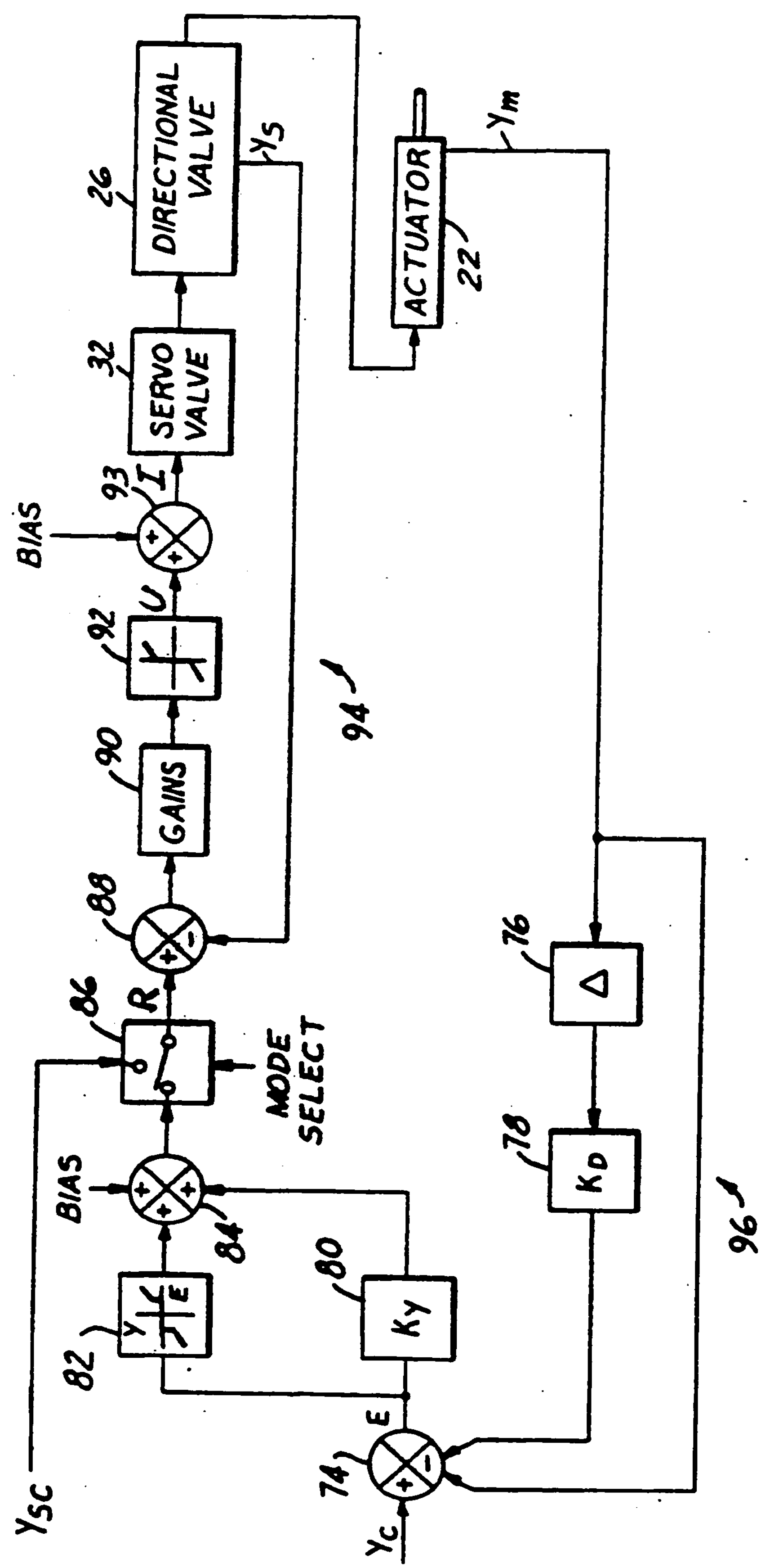
DIRECTIONAL VALVE
SERVO VALVE
ACTUATOR
GAINS
MODE SELECT
BIAS
BIAS
Ys
Ym
YSC
YC
E
R
U
I
Δ
KD
KY
26
32
22
93
92
90
88
86
84
82
80
78
76
74
94
96
34

FIG.5

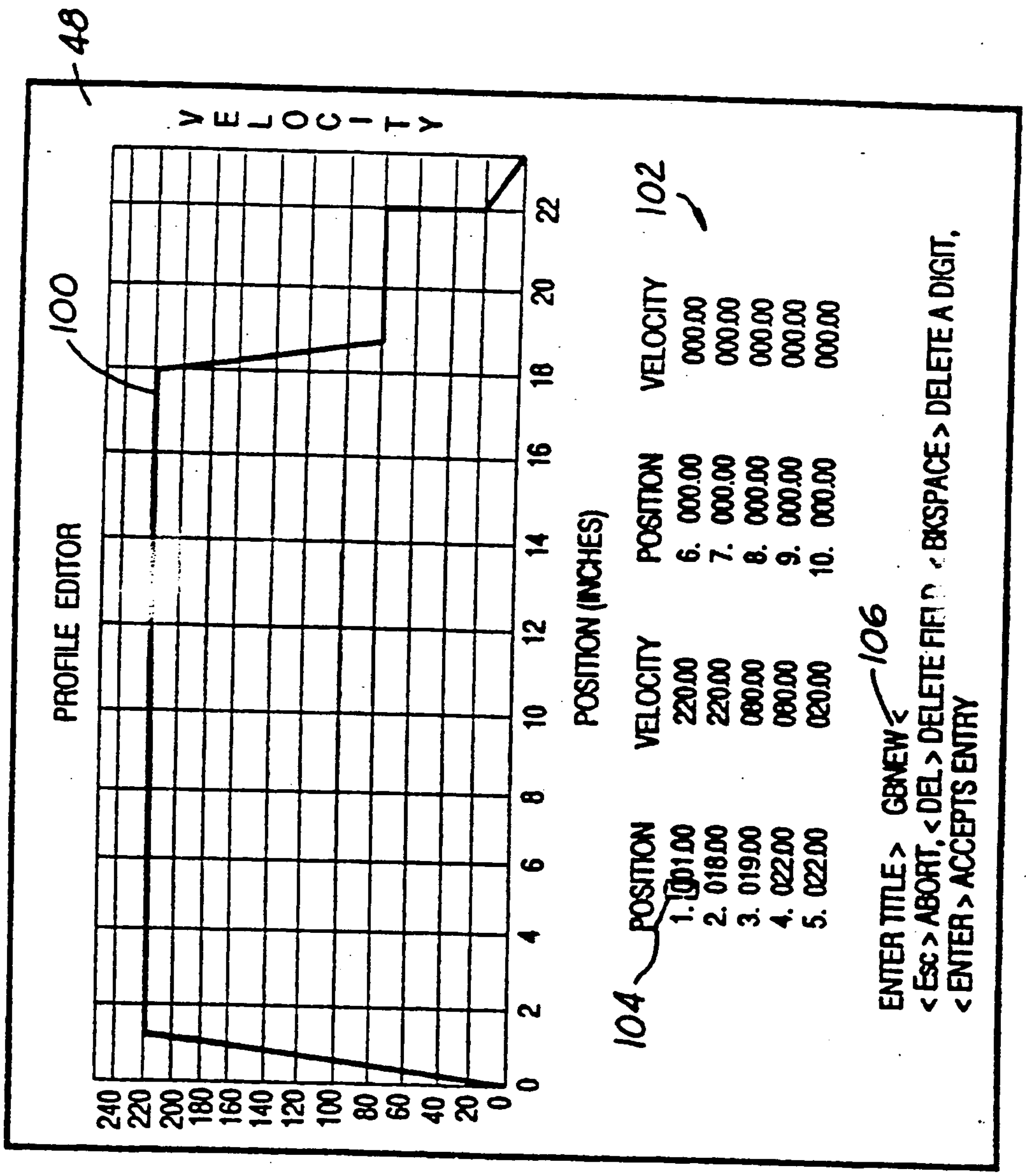
48
PROFILE EDITOR
VELOCITY
240
220
200
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
100
102
POSITION (INCHES)
104
POSITION VELOCITY POSITION VELOCITY
1. 001.00 220.00 6. 000.00 000.00
2. 018.00 220.00 7. 000.00 000.00
3. 019.00 080.00 8. 000.00 000.00
4. 022.00 080.00 9. 000.00 000.00
5. 022.00 020.00 10. 000.00 000.00
106
ENTER TITLE> GBNEW
<Esc> ABORT, <DEL> DELETE FIELD <BKSPACE> DELETE A DIGIT,
<ENTER> ACCEPTS ENTRY

FIG.6

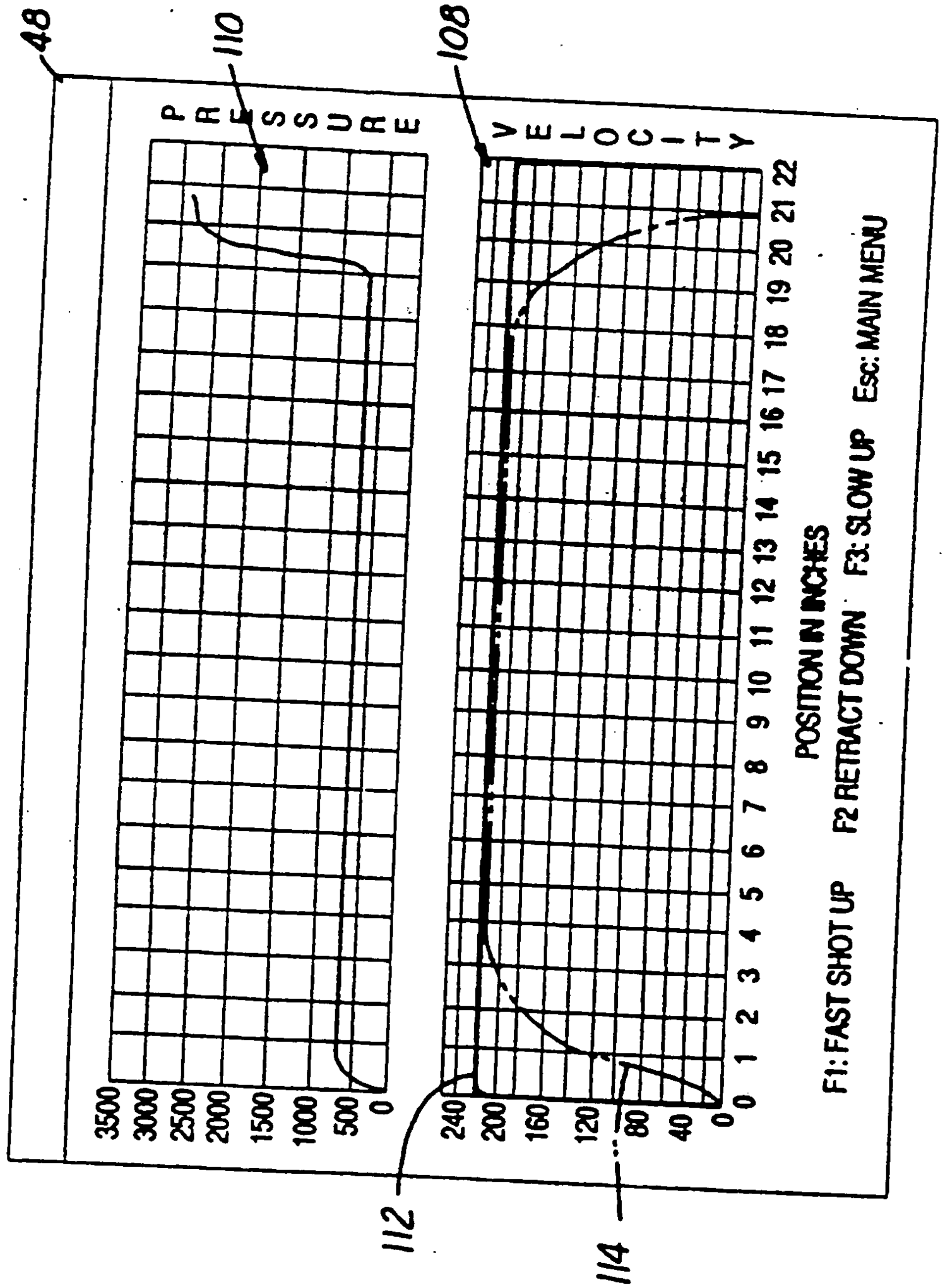
48
110
108
PRESSURE
VELOCITY
3500
3000
2500
2000
1500
1000
500
0
240
200
160
120
80
40
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
POSITION IN INCHES
F1: FAST SHOT UP
F2 RETRACT DOWN
F3: SLOW UP
Esc: MAIN MENU
112
114

FIG.7

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Electrohydraulic system.

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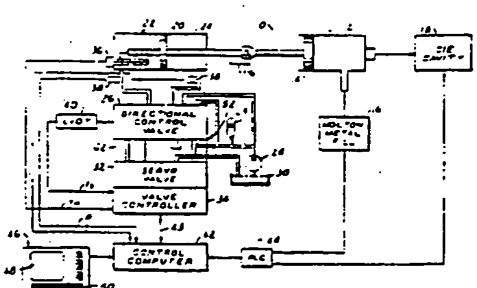

FIG 1

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 90 10 7523

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y,D	US-A-4 635 682 (WALTERS) * the whole document * - - -	1-6	G 05 B 19/407 F 15 B 21/08 B 22 D 17/32
Y,D,Y,D	US-A-4 757 747 (BLATTER ET AL.) * the whole document * * the whole document * - - -	1-6,7-19	
E,Y	EP-A-0 369 173 (SLEEPER & HARDLEY CORP.) * the whole document * - - -	7-19	
A	IBM TECHNICAL DISCLOSURE BULLETIN. vol. 26, no. 3b, August 1983, NEW YORK US pages 1660 - 1661; S.M. Howe and G.M. Schart: "Pneumatic cylinder deceleration system." * pages 1660 - 1661 * - - - - -	1-19	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

G 05 B

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	26 November 90	RESSENAAR J.P.

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
Y: particularly relevant if combined with another document of the same catagory
A: technological background
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P: intermediate document
T: theory or principle underlying the invention

E: earlier patent document, but published on, or after the filing date
D: document cited in the application
L: document cited for other reasons

&: member of the same patent family, corresponding document